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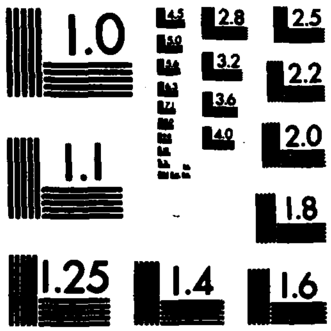

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AN APPLICATION OF A COSTING METHODOLOGY TO WASTE-TO-ENERGY POWER GENERATING UNITS AT REMOTE SITES AND WRIGHT-PATTERSON AIR FORCE BASE

Captain Donald E. Munsey, Jr., USAF

LSSR 107-83

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
LSSR 107-83

2. GOVT ACCESSION NO.
A135517

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
AN APPLICATION OF A COSTING METHODOLOGY TO WASTE-TO-ENERGY POWER GENERATING UNITS AT REMOTE SITES AND WRIGHT-PATTERSON AIR FORCE BASE

5. TYPE OF REPORT & PERIOD COVERED
Master's Thesis

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Donald E. Munsey, Jr., Captain, USAF

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
School of Systems and Logistics
Air Force Institute of Technology, WPAFB OH

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Department of Communication
AFIT/LSH, WPAFB OH 45433

12. REPORT DATE
September 1983

13. NUMBER OF PAGES
108

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Approved for [illegible] IAW AFR [illegible]
LYNN E. [illegible]
Dean for [illegible] Development
Air Force [illegible]
Wright-Patterson [illegible]

17 OCT 83

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Waste-to-energy Conversion	Alternative Energy
Biomass Energy	Renewable Energy
Remote Sites	Refuse
Energy Analysis	Incinerators
Fuel	Facility Energy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Thesis Chairman: Joseph S. Stewart II, LtCmdr, USN

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

This study gives an overview of the current energy situation in the United States and reviews available approaches to alleviate our dependency on non-renewable fossil fuels. The thrust of the study centers on small-scale energy production from waste materials and how the Air Force can make effective use of such technologies. The study evaluated the cost-effectivness of incorporating waste-to-energy incinerators into the power generation systems at remote sites because power generation at these sites poses a serious logistics problem, as was discovered recently at Ascension Island during the Falkland Islands War. Although the sites are geographically isolated and their entire energy supply must be transported in, they are pivotal to the success of our national security plans. Numerous references are cited which tend to support the economics of small-scale waste-to-energy incinerators to dispose of the site's solid wastes while simultaneously replacing some of its petroleum requirements with renewable energy sources. A cost analysis of a waste-to-energy unit at Wright-Patterson AFB showed similar positive results.

LSSR 107-83

AN APPLICATION OF A COSTING METHODOLOGY TO WASTE-TO-ENERGY POWER GENERATING UNITS AT REMOTE SITES AND WRIGHT-PATTERSON AIR FORCE BASE

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Management

By

Donald E. Munsey Jr., BS, FW
Captain, USAF

September 1983

This thesis, written by

Captain Donald E. Munsey, Jr.

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS MANAGEMENT

DATE: 28 September 1983

Joseph S. Stewart II

COMMITTEE CHAIRMAN

READER

ACKNOWLEDGEMENTS

I thank LtCmdr Joseph S. Stewart II, my advisor, for helping me throughout this research project. His guidance and faith in me lifted me out of several very low spots. I also thank Capt Larry W. Emmelhainz, my reader, for his very constructive assistance. Thanks also to Mr. Stephen A. Hathaway of the Air Force Energy Group, and Major George Kastanos of Air Force Logistics Command for their support.

Many individuals helped tremendously with this research, in particular: Mr. William Smith of Marysville, Ohio, who designed the system around which my hypothesis was built; Dr. Mitchell Pedroff of Piqua, Ohio, whose interest in alternative energy is very stimulating; and finally, Dr. Herman J. Heikkenen of the American Institute of Dendrochronology, Blacksburg, Virginia, his expertise and insight into the forest industry was always there when needed. Thanks to you all!

The true credit for this work belongs to my wife, Marsha and son, Ryan. Without their love and patience, it would not have been finished. They have taken the brunt of many long hours and much frustration. They truly deserve credit for a "remote tour" during the last fifteen months. I love you both!

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CHAPTER I

INTRODUCTION

The Department of Defense (DOD), as a leader in high technology applications, has an opportunity to deal with the future use of energy in a cost-effective and realistic way while at the same time reducing the operating cost at selected bases in our national defense establishment. The requirement to convert from petroleum derived energy sources has been mandated. At the same time, it is understood that defense effectiveness cannot be reduced. On the frontiers of our defense establishment are several remote sites which place uncommon demands upon the logistics support system, but are instrumental to the success of our nation's defense plan.

Problem Statement

This paper will show that numerous experts have concluded that, for a variety of reasons, large bases in the continental United States (CONUS) may not be able to profitably convert their energy systems to use renewable energy resources. However, a detailed cost analysis of such units for isolated locations has not been developed.

Objectives of this Research

The objective of this thesis is to obtain cost data on alternate energy sources for these remote sites and to

examine the feasibility of selected options. Specifically, the objective is to determine whether waste-to-energy conversion at remote sites is economically feasible. This thesis will also approach waste-to-energy conversions for CONUS bases, on a smaller scale than has been analyzed before, to determine if small waste-to-energy conversion systems can be cost-effective.

Energy: Availability for the Future

The Executive Summary of the 1982 United States Air Force Energy Plan opens with the following statement: "Energy is central and critical to the operational readiness of the strategic and tactical forces [3:1]." Two major concerns permeate all Air Force and Department of Defense (DoD) energy policies. These two facts affect planning and policy making at all levels because of the Air Force's intensive energy requirements. First, the impact on fuel availability during a time of national emergency should there be a natural or accidental disruption of our domestic energy supplies, or a political or military interruption of the inflow of imported petroleum, such as the Arab oil embargoes of the 1970's. Secondly, the upward trend in energy costs plagues all our planning efforts. For example, Air Force energy costs nearly tripled ($1,875.3 Million to $5,174.3 Million) between FY1975 and FY1981 in spite of a 35 percent reduction in energy usage during that period. Air

Force energy planners expect these costs to double again before the year 2000 [3:1]. Energy industry analysts expect energy prices to increase as well. Dickenson and Moll, co-founders of Synthetic Fuel Associates, developed the long-run price forecast for imported crude oil shown in Figure 1.

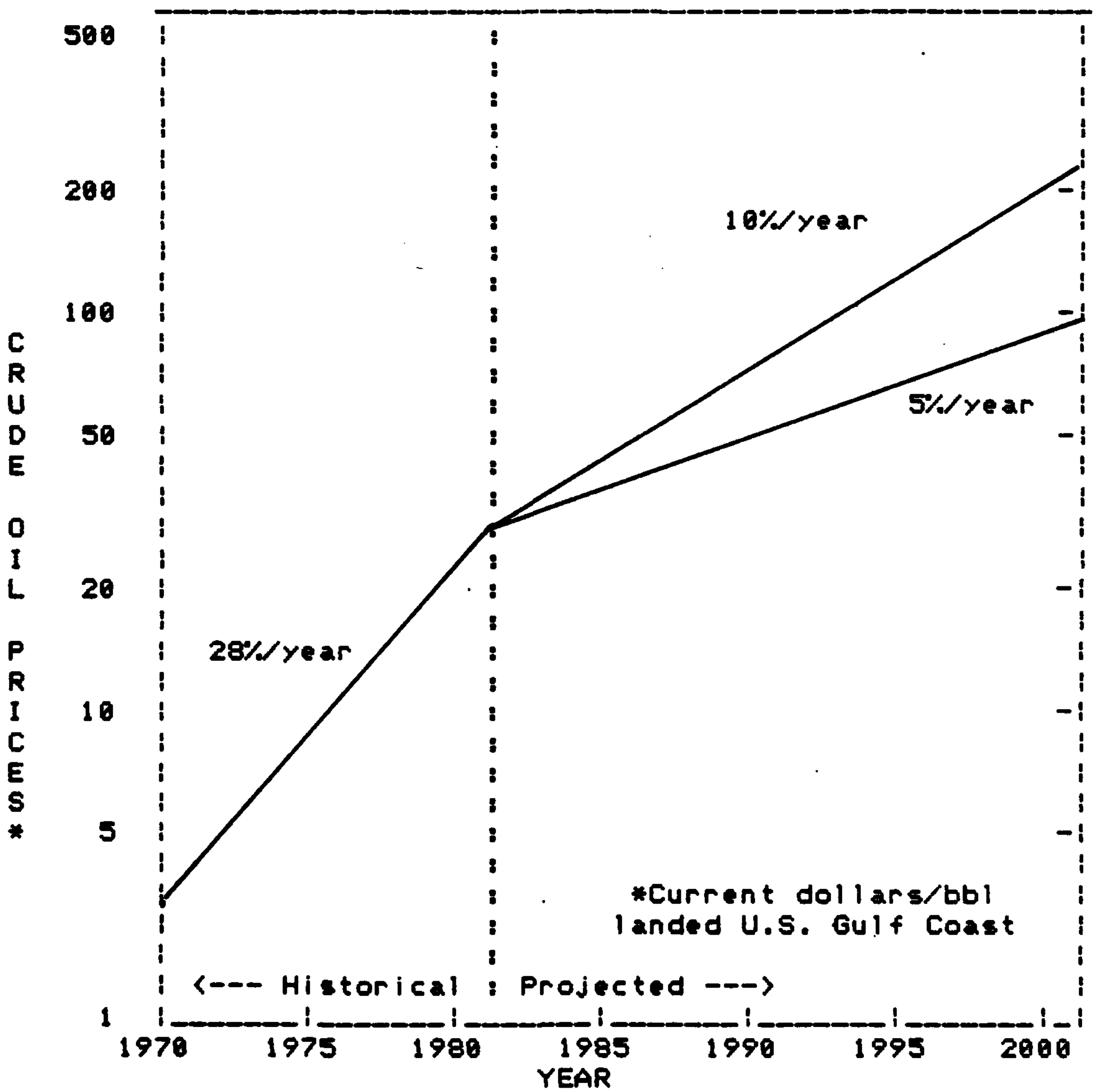

Figure 1. World Crude Oil Price Projection [24:106]

The more optimistic of their estimates calls for a price of $90 per barrel by the year 2000 as compared to the current price of $29 per barrel [24:106].

The overall issue at hand is to develop an effective, comprehensive energy management program, addressing both supply and consumption, which will fill all our peacetime energy needs at a reasonable price without degrading our national security posture. This degradation could result from a significant reduction in our combat readiness as smaller allocations of higher-priced fuels are given to operational units for training in order to avoid using our strategic fuel reserves. Furthermore, the use of stockpiled fuels for peacetime operations, such as training, could seriously limit our response capability during a natural or military emergency. A more devastating scenario would be the evaporation of our energy supplies during a contingency or national emergency as a result of reliance upon waivering, foreign governments to supply increasing amounts of our energy needs.

A significant portion of our petroleum derived fuels are consumed in facilities such as centralized heating and power plants throughout the DOD. For example, during FY1981, 12.3 percent of the Air Force's petroleum-derived fuel was consumed directly in support of facility operations or industrial processes [3:3]. This does not include the fuel

oil and/or natural gas used by commercial utilities to produce the electricity or steam which the Air Force purchased [3:3]. Defense Energy Program Policy Memorandum (DEPPM) 80-6 issued guidance for the Armed Services to use in forming their energy plans, and the Air Force has established specific goals for its more than 3,000 worldwide installations in order to assure compliance. These goals include conversion and conservation programs to reduce petroleum derived fuel use below FY1975 levels according to the following schedule:

FY 1985 . . . . . 30%
FY 1990 . . . . . 35%
FY 1995 . . . . . 40%
FY 2000 . . . . . 45% [3:45-6].

Conservation programs have been and will remain a natural energy source, however, even with increased conservation awareness, world energy usage is projected to be two-thirds higher than present consumption by the year 2000 [29:95]. Emphasis on conversion to non-petroleum fuels is sounder policy. Exxon Corporation supported conversion programs in their 1979 World Energy Outlook. Their prediction of a petroleum production shortfall equivalent to approximately 112 million barrels of oil by the year 2000 is shown in Figure 2 and the immediate need for a strong alternative energy industry in this country can clearly be seen [21:11]. The huge capital investments required to construct nuclear power plants and then distribute the

energy produced, coupled with inadequate energy demands of individual bases make it impractical to consider building nuclear reactors at any of the widely dispersed Air Force installations. Development of non-nuclear, alternative energy sources to support the DOD's rear-echelon facilities can allow significant amounts of fuel money to be diverted into purchases for the strategic fuel reserves for emergency use, or for additional allocations of fuel for combat readiness training of operational units.

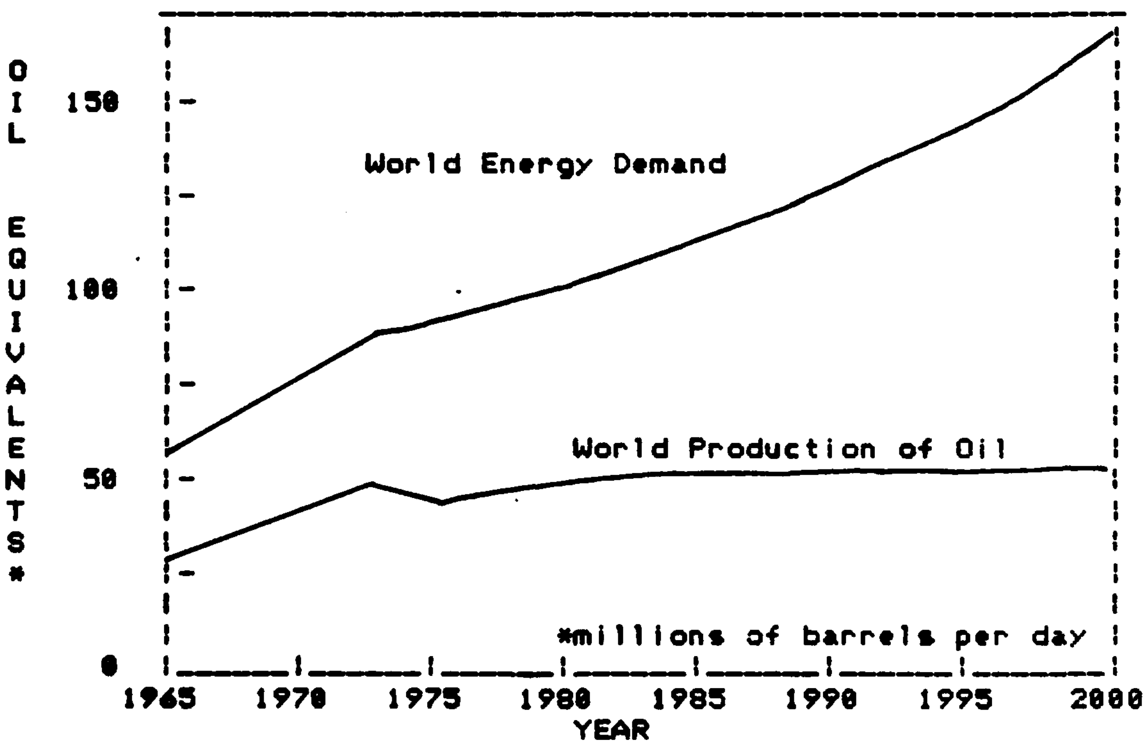

Figure 2. The Need for Alternate Fuels [21:11]

Additionally, by participating in the development of new energy technologies, the DOD will bring nearer the day when

the entire nation's energy requirement can be met with domestic, renewable resources instead of foreign or fossil fuels such as oil, natural gas or coal. To assist this development, the Air Force Energy Office has set the following schedule for renewable energy use at its installations:

FY 1985 . . . . 1%
FY 1990 . . . . 5%
FY 1995 . . . . 10%
FY 2000 . . . . 20% [3:46].

There are many costs and benefits of alternative energy programs. Some are easily quantifiable and others are not, but all of them must be considered in our planning efforts to meet these goals [66:2].

The existing centralized heating and power generation infrastructure of many Air Force installations provide an opportunity to test the development and operation of many of these new energy strategies. Many of these generating plants are nearing the end of their useful life and will soon require extensive upgrades or replacement [54]. One seldom considered alternative is the establishment of smaller, auxillary power generation units capable of being tailored to local fuel supplies at individual installations [50]. These distributed processing units can be located where they will directly supply the energy needs of a particular facility on the base, such as a warehouse, aircraft or vehicle maintenance shop, mess hall, or even a

hospital. However, so that the target facility would never be without power, the auxilliary power units must be part of the installation's overall power supply system. This interface should also allow input into the installation's overall power distribution system of any excess power produced by the small units. This additional power supply will reduce the demand on the central unit and could have many advantages, some of which are: 1) extended life of the main facility as it would not be required to operate at or near maximum capacity as often, or 2) replacement of existing facilities with smaller scale facilities thus creating future cost savings [45; 50; 61].

Waste: The Problem of Disposal

Another significant problem under constant review by planners and decision makers is the large amount of solid wastes which are generated daily at all Air Force installations. (The wastes referred to here are not the hazardous or toxic wastes receiving so much attention in today's press. Although a serious problem in their own right, hazardous and toxic wastes are beyond the scope of this study. Neither will this report consider the energy supply resources of raw or treated sewage.)

Solid waste production in the United States has increased steadily over the past several years. Growth rate estimates range from 1.04 to 8 percent annually and are

expected to continue this trend into the mid 1980's (see Table 2). Solid wastes are generated continuously on military bases by personnel living in military family housing and the barracks, the industrial operations and administrative activities of the organizations assigned, the dining and recreational facilities, and the commissary and exchange operations. In other words, solid waste generation is universal. "Sanitary landfilling" is the primary method of disposing of this waste material in this country today. The steady increase in solid waste, coupled with public concern about landfills, has caused sites for use as landfills to become more and more difficult to find. The increased distance between the centralized military installation and the waste disposal site has caused an increased price in the contracts required to secure a collection contract for military refuse. Increased truck fuel costs, increasing gate fees at the landfills, and "unproductive" time for crews and trucks while traveling to and from the disposal site are cited as significant reasons for this increase [57; 68].

An Integrated Solution

The two problems above, energy and wastes, create an unique opportunity for a mutual solution. Conversion of waste into usable energy is thought to be one of the most acceptible solutions to both of these problems [26:11].

Waste-to-energy production units have been in operation since 1954 when the first successful plant in Berne, Switzerland was opened [25:308]. Since then, numerous successful ventures have been started in Europe, Japan, Canada, and Scandinavia [1:27]. More recently, Lappen reported that "as of May 1981, 29 plants in the United States were using direct incineration or co-firing of refuse-derived fuel (RDF) for energy recovery [58:50].

Waste-to-energy systems can be divided into three classes: 1) those which directly incinerate the waste with little or no preparation; 2) those which use prepared RDF because of its lesser volume and better handling characteristics; and 3) those which use wastes as a feedstock for a chemical reactor which produces synthetic fuels such as ethanol, methanol or crude oil.

Although military installations generate the greatest amount of solid and liquid wastes and use the greatest portion of the total energy consumed in the government [2:1,41], planners still in general feel that not enough solid wastes are generated by these installations to justify development, construction and operation of waste-to-energy units at individual bases [3:56]. This may be true if: 1) solid wastes are considered the only fuel available, 2) only large scale operations are planned, or 3) only bases in the continental United States are studied. There are therefore

two situations where small-scale waste-to-energy units should be further studied. First, if other waste fuels, including agricultural and forestry wastes, are solicited from the surrounding community, or secondly, when remote site operations are under consideration.

Research Hypothesis

Many Air Force remote operating locations are strategically pivotal as early warning radar surveillance sites or refueling and staging bases. They also are dependent on air or seaborne petroleum for all their energy needs. These sites are also located where real estate for landfills is extremely limited (island stations), or unsuitable (tundra or desert bases). These characteristics of the remote sites accentuate the seriousness of energy and waste problems. Therefore, it is the hypothesis of this research that: A small-scale energy unit, using fuels derived from wastes or biomass, can be incorporated into remote site energy systems for a reasonable cost, which will contribute to the alternative energy goals for the site, while simultaneously helping to solve the site's solid waste disposal problems.

A secondary hypothesis is that: similar small-scale units could be incorporated at installations within the continental United States which are either geographically isolated, or are isolated from their primary fuel supply.

Plan of the Study

This chapter has outlined the general environment for military energy research. The next chapter will explore the vast amounts of literature published concerning renewable energy resources, solid waste management, and the possibility of a mutual, integrated solution to problems in both areas simultaneously. Chapter 3 describes the methodology used in data collection and analysis. An economic analysis is performed in Chapter 4 to determine the period of time required to payback waste-to-energy plant construction costs. Finally, Chapter 5 details the conclusions drawn from the analysis of Chapter 4 and proposed several recommendations for further study in these areas.

CHAPTER II

LITERATURE REVIEW

The Overall Energy Situation

> In his energy address of 1932, Adolph Hitler appealed to his bedraggled countrymen for support in developing a synthetic fuel industry saying, "An economy without oil is inconceivable in a Germany that wishes to remain politically independent." Fewer than 10 years later, Rommel's tanks crossed northern Africa on fuel supplied by some of the 19 synfuel plants built to convert coal into gasoline and diesel fuel.
>
> In his energy address of 1979, Jimmy Carter appealed to this country for support of a synthetic fuels industry 20 times larger than the German World War II effort. He called the fight for independence from foreign oil "the moral equivalent of war" [78:13].

The need for a domestic, self-sufficient energy system in the near future is of paramount importance to our nation unless we want to become economic and political hostages of the oil producing nations of the world. The transition to self-sufficiency can only be realized through conservation efforts and enhanced domestic production, using an array of technologies. Classic cost/benefit or return-on-investment analyses fall short in this situation. Dr. Richard A. Stimson, Director of Industrial Productivity, Office of the Secretary of Defense, feels that these types of analysis, which maximize short-run performance and in general ignore the political and economic ramifications of not investing, will indicate that new energy technology

should not be attempted [88]. But, what long or short-term benefit or return can be realized if our military or industrial complex runs out of energy?

<u>Domestic Climate</u>. Following World War II, an era of cheap energy brought about our country's headlong rush into a petroleum-based economy. Government energy policies during the last 50 years have been detrimental to the development of a domestic energy industry other than the centralized fossil-fired public utility system. In fact, during the 1930's and 1940's the government virtually stopped all research and development in the wind energy industry when the Rural Electrification Administration required individual land-owners to dismantle their private windmill systems as a prerequisite for electrical hookup [81:60]. This increased the centralization of our power production grid under the guise of progress. In the 1950's and 60's foreign oil was plentiful and priced considerably lower than oil produced in this country. Under pressure from domestic producers, programs limiting oil imports and supporting domestic prices were established by the federal government in an effort to induce increased exploration and refinery productions [4:58].

> The irony of the policy, however, was that it tended to induce an over-rapid rate of recovery from domestic reserves and thus contributed to an increased reliance on foreign supplies leaving this country vulnerable to the so-called energy crises of the 1970's [59:80].

In fact, a 1979 analysis of oil company budgets [89:42] showed that exploration and drilling expenses had increased, but that proven reserves had continued to decline. Robert Stobaugh, director of the Energy Project of the Harvard Business School, interviewed an oil company executive who summed up the shortfall of these policies in the following fashion: "Sure, higher prices will help, but a bigger factor is access to new acreages. Even a price of a hundred dollars a barrel won't give oil unless you have some place to drill" [89:42].

There were several other government policies which had detrimental impacts on our domestic oil exploration and production. First, environmental regulations requiring automobiles to burn unleaded fuels forced refinery upgrade investments which detracted from domestic exploration and production activities [4:155]. Second, tax reform legislation drastically reduced the amount of oil industry profits excluded from their federal tax liability [86:12]. Lastly, the Economic Stabilization Act of 1970 placed price ceilings on home heating oil which were based on off-season, summer prices and demand [4:143-8], and placed mandatory controls on all petroleum product prices [86:136]. These government policies left our domestic, petroleum industry in a depressed state of production, and the nation ripe for exploitation by oil producing nations.

When the oil producing countries discovered the value of crude oil as a political lever in the early 1970's, the US government was forced to implement price ceilings on gasoline. These policies were designed to assure all consumers had access to the existing supply in an equitable manner as the demand for petroleum products surpassed the limited supplies. Gasoline shortages soon became severe however, and the government had to ration the limited supply using non-pricing schemes (generally these schemes restricted the time or volume of sales). These rationing schemes actually caused the real price of gasoline to rise above the ceilings because considerable time and fuel were wasted waiting in long gasoline lines. Leftwich feels that the market would have stabilized at a lower price on its own and rationed the supply in a more equitable fashion [59:82]. These ceilings remained in place as market prices declined and gasoline lines abated, but in 1979 the situation recurred during the Iranian suspension of crude oil supplies and market prices rose to surpass the ceilings once again. The United States Department of Energy aggravated the situation by requiring refiners to produce more home heating fuels than they would have and by implementing an allocation scheme which accentuated shortages in densely populated urban areas of the country [59:83]. If a domestic, alternative energy infrastructure had been operational at

that time, these difficulties might have been substantially less.

The foreign dependence and social disruptions these government policies brought about increased the public's awareness of the economic and strategic vulnerability of this nation's energy supplies. This awareness was highlighted in a speech by Richard J. Goeken, President of Gulf Mineral Resources Co., to the Society of Petroleum Engineers in September 1980. He stated that this vulnerability "necessitates a maximum effort to develop all forms of energy" [37:84].

The recent energy crisis was indeed an economic crisis. An ever increasing proportion of the budget of every economic concern must still be diverted from productivity improving capital investments to the energy expenditures necessary to operate at current levels of production. Because approximately 96 percent of that energy is currently derived from nonrenewable resources, in spite of the recent tumble of crude oil prices (a result of disagreement between members of the Organization of Petroleum Exporting Countries (OPEC) cartel), overall energy costs can do nothing but rise steadily as the cost to produce each successive unit of fuel increases [20:1]. Additionally, there is another hidden cost of higher energy prices. Many government agencies are having to provide

subsidies to individuals who cannot pay their utility bills. This increases the welfare burden on the rest of the tax paying populace [23:x].

Unlike manufacturing industries where economies of scale create decreasing marginal costs, Barry Commoner, director of the Center for the Biology of Natural Systems at Washington University, has found

> as it becomes more and more difficult to take oil out of the ground, more and more energy will be needed to lift the oil (or coal), and there will come a point at which the energy content of the oil that is taken out of the ground becomes equal to the energy used. Unless there is some spasm of insanity, we will stop producing oil (or coal). Thus, the energy crisis is not the distant, abstract fact that we are running out (of fossil fuels), but the immediate, practical fact that the cost of energy keeps rising [20:1],

or more plainly, "we are running out of cheap oil and gas" [45:207] and coal [92:xix-4].

Domestic Non-renewable Resources. Energy industry literature currently emphasizes the development of a synthetic fuel (synfuel) industry in this country [24; 51; 52; 76]. The primary thrust of this literature concerns large-scale production of synthetic fuels, derived from other lower grade fossil fuels such as oil-shale, tar-sands and/or coal [29; 104; 105], which can be used as direct replacements for conventional petroleum products. Why has so little been done to develop a viable synfuels industry in this (or any other) country in recent times? The reasons

are very complex. However, unpredictable government energy policies (or the lack of any policy at all), conservation softened demand, and artifically depressed prices are generally blamed for having relieved pressures which otherwise should have occurred due to dwindling world-wide supplies of petroleum. M. G. Fryback, manager of Sunoco Energy Development Company's Synfuels Division, broadly categorizes the primary stumbling blocks in bringing synfuels to the marketplace as 1) economic, 2) environmental and 3) regulatory. More realistically, he consolidates these into project economics because the environmental and regulatory aspects both exert direct and indirect pressure on project costs [34:39].

These stumbling blocks are especially valid when considering those segments of the synfuels industry pursuing direct fossil fuel (coal, oil and natural gas) replacements on a large scale similar to that which exists today in the petroleum and utility industries. Private industry can adjust production levels to cope with changing price levels and demand, but unpredictable shifts in government policy adversely affect large, long-term projects and create an atmosphere of unacceptable risk which causes delays in investment decisions. For example, special interest politics have impeded the development of an octane enhancer to replace tetraethyllead (the least cost alternative

[6:15]) in order to meet federal Clean Air Act standards [24:109]. Not only are environmental standards under constant revision, but efforts to support a gasohol program, in order to shore up corn prices, have artificially suppressed gasohol prices and given ethanol an economic edge [55:78-9], but not necessarily a chemical edge as an octane enhancer. Therefore, resources have been diverted from other promising efforts, such as methanol, which are cheaper even without the aid of subsidies and may prove to be better than ethanol [6:14-5; 24:109; 55:78-9]. Union Oil Company's oil-shale project at Parachute Creek, Colorado, due to start production with government price guarantees in July 1983, offers the best immediate hope of a successful synfuel industry since Exxon recently abandoned its Colony oil shale project [51; 104].

Direct Replacement Programs. An estimated $550 million will be spent by Union Oil to complete the first phase of its Parachute Creek project [104:71]. These huge amounts of capital required for process development and infrastructure, coupled with current unstable crude oil prices and supplies, and high interest rates have created a need for government aid to the young synfuels industry [76:4]. In fact, Milton Russell, director of the Energy Research Division of Resources for the Future feels that "selective intervention by the state in energy matters can

speed and smooth the process of getting from where we are today to where we want (and need) to be [80:41]". The United States Synthetic Fuel Corporation (SFC) was created by the Energy Security Act of 1980 to address these needs. Its purpose was to stabilize government energy policies and

> allow attainment of significant synfuel production in a timely manner and in a manner consistent with the protection of the environment requiring financial commitments beyond those expected to be forthcoming from nongovernmental capital sources under existing governmental incentives [51:23].

For larger scale investments, government support for alternative energy has come in the form of federal price guarantees, purchase contracts and grants from the SFC to cover start-up and initial production costs (as is the case with the Union Oil's Parachute Creek project) [104:71]. Although Union Oil Company required federal assistance to begin the venture, their policy for continuing is: "government support should come only for the first plant. Then it (the synfuels industry) should be left to market forces [104:75]." Until 1984, only the first phase will be operated at Parachute Creek. If at that time, a favorable outlook for shale crude prices, and the infrastructure socioeconomic impact exists, Union will begin expansion without government support (they will not request it), thus placing the future of shale crude into the hands of the free market [104:72-3].

The Department of Defense, as an interested customer,

is supporting the development of the oil shale industry on a regional basis. For example, in an attempt to reduce its strategic dependence on foreign aircraft fuel sources, the Air Force has supported development of and contracted for the delivery of aviation fuel (primarily JP-4) derived from domestic, oil shale for use in F-16s at Hill AFB, Utah. The Fuels Division of the AF Wright Aeronautical Labortory at Wright-Patterson AFB, Ohio has just completed a potential value study of the JP-4 derived from oil shales and, since the production of this JP-4 leaves a significant amount of residue, they are performing a similar study of the energy potential of oil shale residues (OSR) [41]. As this production of JP-4 increases, the AF accrues increased amounts of these residues which must be disposed of or used [43]. OSRs, which are not suitable for direct replacement of heavy heating fuels, offer a potential starting point for the development of an alternative energy program for Air Force installations throughout the southwestern United States.

In 1981 Hatch and Mansfield defined self-sufficiency for Air Force Logistics Command (AFLC) as follows:

> The Air Logistics Centers (ALCs) should have the capability of producing their own energy for a thirty to sixty-day period by utilizing stockpiled resources such as coal, RDF, or waste or through use of energy sources such as solar that do not require stockpiled reserves. This requirement would be based on the needs of the industrial facilities and processes and on an austere level

for all other depot activities. The depots should utilize the most applicable energy technologies available to them considering regional as well as demand and other requirements [42:125]

Planners at AFLC are working toward command-wide energy self-sufficiency by the year 2000 and they believe that OSR can and will make a significant contribution, especially at the Ogden ALC and at Hill AFB near Salt Lake City, Utah [54].

John M. Hopkins, president of Union's Energy Mining Division stated, "It's a certainty that an oil shale industry will eventually need to be in place in the United States [104:75]." However, an over reliance on oil shale, which is also a depletable energy source, could lead to the same problem of escalating energy costs as each barrel of shale crude becomes more expensive to produce.

Raw material availability presents another problem associated with finite fuel systems as many prime oil shale and coal lands are federal property and are not available for commercial development under current policy [103:55-6]. Furthermore, locating large facilities where they can make use of all available economies of scale without devastating the environment is very difficult and, in fact, leads to the design of even larger facilities [70:13-4]. This is extremely dangerous because even a small miscalculation in projected demand could commit funds for a project which when completed years later will be so oversized that all

economies will be lost to unused capacity [70:21]. One only has to look at the underused plants of the US auto and steel industries to see the devastating impact of this type of error in responding to unstable, short-term demand or failure to forecast the impact of technological change. Dr. Richard T. Taliaferro, head of the System Acquisition Management Department at the Air Force Institute of Technology, summed up this situation in reference to technological unemployment as follows:

> Capital put in place yesterday to satisfy existing demands may be idle today because of the lack of its adaptability for satisfying changed demand patterns and because it is not readily moved to new geographical locations in response to population shifts [91:224].

<u>Scale of Production</u>. The renewable energy industry is affected by these problems to a significantly lesser degree. There are energy analysts who believe the proper response to President Carter's appeal for our energy independence should lie in the number of producers involved, not their size [70:15]. A lower initial capital investment allows more firms to enter the marketplace giving the consumer the benefit of increased competition and localities the benefit of increased employment opportunities. For example, the solar collection industry approaches the ideal of pure competition. As late as 1979, no manufacturer held more than 3% of the market [63:188-9]. Additionally, smaller facilities which are less capital intensive reduce

development leadtimes [37:85; 45:216; 63:188-9]. Finally, in breaking with the economic tradition that large industrial complexes produce cheaper products, there is evidence that the savings derived from the mass production of small scale production equipment will outweigh the economies of large scale production of energy itself [61:87; 45:216].

The socioeconomic impact of a centralized synfuels industry, with its huge infrastructure requirements, can be beneficial to only a few local economies. For example, Union Oil's payroll at Parachute Creek is expected to average 1500 personnel (including 80 of their top management people) during the next year and will stabilize at about 450 when normal operations are underway. The infrastructure to support these people has dumped $60 million (more than 10% of the project costs) into a community expected to number only 2500 citizens. The results of these monies can be seen in new dwellings, rebuilt and new roads, and new community facilities such as schools [104:73,75]. However, these benefits can be realized by only a few other communities if the synfuels or alternative energy industry remains centralized.

There are tremendous advantages to be gained by our country entering into an aggressive energy policy which places increasing emphasis on smaller, decentralized production units in a manner analogous to the "distributed

processing" philosophy which is allowing quantum leaps in productivity to occur in the data and information processing industry. The establishment of small, widely distributed units, in lieu of large generating stations, allows several interesting things to happen. First, because of reduced size (and consequently smaller capital requirements), shorter construction times will allow planners to respond more readily to arising changes in technology. If an ongoing project has progressed too far to allow incorporating new changes, they certainly can be incorporated into successive projects without waiting nearly as long for the new technology to become operational. In a large centralized system, once the system finally becomes operational, a large proportion of production must necessarily use obsolete, inefficient processes because so much capital has already been invested. An example from the financially strapped steel industry illustrates this point clearly.

> At home, the major steel producers also seem certain to lose sales to the minimills, which have already increased their share of the U.S. market from less than 3% in 1960 to 18% today. Minimills, which melt scrap in electric furnaces to produce steel, have an edge over conventional steelmakers because they have more modern plants and advanced technology. More than 75% of the steel that the minimills produce is continuously cast. This aggressive use of technology, plus the fact that most minis are not unionized, enhances productivity and lowers employment costs. For example, F. Kenneth Iverson, president of Nucor Corp., an operator of seven minimills with headquarters at Charlotte, N.C., says his

employment costs average $65 per ton vs. $160 per ton for the major producers [94:86].

The distributive nature of renewable energy production will yield several other advantages. First, there will be a reduced impact from a plant failure. The impact of a 100 megawatt generator failure will be much less widespread than the failure of a 1000 megawatt plant [61:87]. Secondly, small scale units make sense from a systems management point of view. Modular units can be added as required near their service areas, reducing the extensive distribution system required by centralized units [45:216]. For example, Virginia Electric and Power Company which serves approximately 32,000 square miles in portions of Virginia, West Virginia and North Carolina, requires 42,502 miles of above ground lines and 10,775 miles of underground lines to distribute the electricity it produces [100]. Estimates vary, but indicate that between five and fifteen percent of all electricity generated is lost during high voltage transmission [70:19; 47:480-1] and 35% of utility capital expenditures in 1974 were for distribution equipment [61:87].

Energy load management is facilitated in distributed units because the difference between base loading and peak loads is not as great [47:481]. Stephen J. Gage, vice-president of the Science and Technology Laboratories at International Harvestor, describes an internal study showing

that modular, packaged methanol plants which can be mass produced and transported to operational sites can be economical, and their truly portable nature allows collection of energy from smaller, disconnected sources [40:24]. Distributive energy systems impose both their costs and benefits on the same people and locations. Centralized facilities often impose their costs near the facility, while the benefits are reaped in a distant demand center [50:208]. For example, the New Orleans City Planning Commission found that when a plant is outside the "local economic sphere" there is a leakage of capital for investment and consumer purchases, and therefore a slowdown of local economic growth [102:12].

This trend does not occur if a site specific local energy facility is developed using renewable energy sources. Two important reasons for this are: 1) as one facility is completed, there will be additional facility requirements in the immediate area, because the construction of alternative energy systems is expected to follow the short, cyclical patterns of residential and commercial construction which are more temporal than spatial; and 2) some of the same workforce which constructed the facilities can be expected to remain and perform maintainance on them, thus reducing the level of worker migration from an area [50:206]. Additionally, the scale of a centralized power

generation system does not allow differientation of customer reliability needs; short term disruptions may only be an inconvenience to smaller consumers, however, all must pay for the high reliability requirements of installations such as hospitals, skyscraper elevators, mass transit, traffic control [61:90-2], and military operations. These facts point out many advantages of decentralized energy operations. Therefore, the AF (or DoD) could strengthen its position as a contributing member of the local economies surrounding its installations by establishing its own distributed energy production facilities.

Two recent government policies have provided incentives to smaller firms wishing to increase our domestic energy supply by independent contributions to the nation's power grid. Federal and state tax credits ranging from 40 to 50 percent of the capital investment required and a 1978 law requiring utility companies to purchase power from independent suppliers on the basis of premium costs (the costs to produce power using their most expensive fuels) have allowed many new firms to enter the alternative energy industry that otherwise could not have because of low or negative projected returns on their investments. For example, in the Altamont Pass wind farms near Livermore, California, 50 kilowatt wind turbines produce electricity for approximately 11 cents per kilowatt. Pacific Gas &

Electric's (PG & E) avoidable costs are between 5.3 and 7 cents per kilowatt. Without the tax credits, these projects would not have been started. However, with the current inflow of capital, monies are available for research and development which may soon bring the cost of wind energy down to levels below PG & E's premium costs [81:60].

Domestic Renewable Resources. The best long-term solution to our energy problems is a transition to a broad-based, renewable energy economy. Barry Commoner proposes that

> the sole renewable source of energy available to us now is 'solar' energy. Energy-sensible solar technology is now technically feasible and is either economical today or can be made economical by an administrative stroke of the pen. The technology includes solar collectors for space heat and hot water; windmills; hydroelectric power (especially from existing small dams); fuels derived from plant-produced organic matter, such as wood, or alcohol made from corn (plants get their energy, photosynthetically, from the sun); and devices such as the photovoltaic cell that converts sunlight directly into electricity [20:2-3].

These technologies will permit the development of a systematic and progressive solution to our energy problems, rather than attempting to solve the entire problem with a single solution. William F. Kieschnick of Atlantic Richfield supported this when he stated,

> Another factor in the failure of synfuels thus far has been our stubborn refusal as a nation to set realistic production targets. Americans like to do things in a big way, which may explain why our synfuels planning has been so exaggerated [56:26].

Supplies of renewable energy resources, being domestic, will not be subject to unstable availabilities resulting from fluctuating politics among oil producing countries. However, our own legal and political systems must be controlled in order to successfully transition to a more self-sufficient energy posture. For example, a refuse collection ordinance designed to provide a constant supply of refuse for the waste-to-energy plant in Akron, Ohio has been challenged in the courts by area solid waste facility operators [53:32]. Additionally, there is concern that transportation tariffs may adversely discriminate against recyclable materials, including alternative fuels [75].

Fryback has defined three components of any synfuel costs as: 1) feedstock costs, 2) all other direct operating costs, and 3) capital based costs, including profits [34:41]. These cost elements apply to any alternative energy program with one important difference. Renewable energy sources are dominated by labor and capital costs and not by depletable feedstock costs, and therefore, will allow overall energy prices to stabilize in the future [80:40]. Additionally, because solar energy is a flow and not a feedstock, the basic fuel is without cost; consequently, technological advancements to meet increased demand for renewable energy sources should lower their price permanently, whereas even technological improvements in

finite fuel use efficiency cannot indefinitely forestall their depletion [45:157; 63:185]. This can best be described as a manifestation of the theory of learning in the workforce. The development of existing technologies has already extracted the majority of productivity improvement possible. "Fewer and fewer bottlenecks remain to be uncovered [48:97]" by engineers, contractors and operators because of the design and construction of the numerous units already in use. However, the alternative technologies offer more opportunities for increased learning, leading to improved quality and efficiency of production units as successive units are brought online.

Indirect Replacement. Technologies to replace fossil fuels being used in space heating and process energy applications generally fall into several categories based on feedstock converted to an energy form useful by the end user:

1. Direct Solar
2. Nuclear
3. Geothermal
4. Wind
5. Wave
6. Biomass.

Some of these applications (i. e. nuclear) are clearly not feasible for remote site operations because of disparities between the scope of site operations and the minimum size of reactor required. Therefore, the use of nuclear energy will

not be considered in this research.

Studies at the Hawaii Natural Energy Institute indicate direct solar, biomass, geothermal, wind and wave energy programs potentially could alleviate the energy problems of many remote sites, particularly the island sites which are largely dependent on seaborne petroleum for their energy supply [84]. However, of the alternative technologies, only biomass can provide an integrated solution to both energy and waste problems. Consequently, biomass energy resources and their potential use at remote sites will be the subject of the remainder of this research.

Biomass has several definitions, including: "all products of photosynthesis, such as wood, corn, and algae, as well as human and animal wastes [77:1]" and "any organic matter which is available on a renewable basis, including food, feed and fiber crops and agricultural wastes and residues, animal wastes, municipal wastes and aquatic plants [98:394]." Studies concerning energy self-sufficiency using residual fuels within the DOD began as early as 1968 when Bauer surveyed the natural and energy resources available for DOD use [13]. In 1973, two Rand Corporation reports [26; 27] considered the economic aspects of biomass energy production for the nation as a whole and specifically for the state of California. The conclusions at that time were

that a large-scale agro-energy industry would require complex integration with the existing agricultural system, thus making it impractical on the national level. However, "organic wastes might prove to be of greater significance on a local level in cases where large concentrations of waste are generated within a small area [26:22]. In a parallel study, the potential value of unharvested wood residues for near-term use in "small nearby space-heating applications -- especially for peak winter conditions" was demonstrated [17]. In 1978, Lowther studied the feasibility of using Air Force forestry holdings as alternative fuel sources at selected bases [62]. In 1981, this study was expanded and included a specific plan to convert the central heating facilities at Eglin AFB, Florida to use wood fuels (both primary and residual sources) [15].

There are three basic technologies applicable to conversion of biomass to usable energy feedstocks: direct burning, fermentation, and pyrolysis. The United States Department of Agriculture [98:394-7] defines these terms as follows:

<u>Direct burning</u> Combustion of solids, liquids and/or gases to produce heat energy without any other energy separation process. Normally refers to the burning of dry solids of biomass such as wood, wood residues or other plant material.

<u>Fermentation</u> An enzymatically controlled anaerobic breakdown of an energy rich compound. For example, a carbohydrate such as in corn to produce carbon dioxide and alcohol.

(Anaerobic is without the presence of free oxygen.)

Pyrolysis — Chemical changes brought about by the action of heat, as applied to waste. The waste is chemically decomposed in a closed system by means of heat. The waste is converted to fuel gas, oil, char, and water containing some dissolved organic compounds.

A 1980 study by TRW Inc., for the U.S. Armament Research and Development Command found that the energy requirements of the National Space Technology Laboratories and the Mississippi Army Ammunition Plant's could be met using wood-fired power plants. Logging and sawmill residues from the area and management of their 130,000 acres of forest lands will provide the feedstock for these facilities. TRW recommended these feedstocks be secured through direct trade agreement with local private industries, i.e. the private sawmills would exchange equal values of residues for the timber resources on the installations. Direct trade agreements will assure a less expensive, continuous fuel supply than contract sales of the timber and subsequent purchase of fuel feedstock because the proceeds of timber sales would be added to the treasury and each installation would have to compete in the budgeting process for money to purchase logging and sawmill residues through the contracting procedure. The administrative and contract overhead costs avoided by direct trade agreement will significantly lower the costs of the fuel feedstock. Additionally, TRW's findings indicated that only direct

combustion and pyrolysis were applicible conversion technologies and of these the spreader stoker type furnace for direct combustion best met all design criteria [65]. A similar study in 1981 by the U. S. Army Corps of Engineers, recommended, on a broader scale, that wood-fired combustion plants, especially spreader stokers, be given favorable consideration in all normal facility planning throughout the Army between 1983 and 1988. Although the study found little economic data for wood as an energy source, cost estimate ranges were given for different applications [19].

Two problems which reduce the economic return from a wood burning (in fact, any biomass) system are transportation and material handling, especially if the fuels are bulky or widely distributed [83:6]. Fedors showed that transportation costs made co-firing a refuse derived fuel with coal economically infeasible in studies at Wright-Patterson AFB, Ohio [30:79]. The problems of handling bulk wastes can not easily be solved, but at remote site operation the wastes will not be widely distributed, thus collection and transportation will not be a major problem in waste-to-energy systems.

A 1981 U.S. Army Construction Engineering Research Laboratory report developed a plan for assessing the potential of forest resource use in energy conversion plants. The report also included an extensive annotated

bibliography of biomass related publications. The conclusions were: 1) some gaps in technology may make biomass use impractical, specifically, harvesting equipment is expensive; and 2) legal constraints concerning resources managed by the military favor purchasing biomass feedstock in order to return the highest value possible to the government [10:25]. A 1981 study by the Government Accounting Office (GAO) also identified residual energy supplies as one way the DOD could increase its earnings from the natural resource lands it holds [99].

The Piqua, Ohio city schools recently found a notable solution when faced with one oil-fired elementary school whose hot-water heating system was consuming approximately 11 percent of the district's entire energy budget. This building used 18,500 gallons of oil ($18,931) to heat its boiler during the 1982 heating season. When the building's boiler was converted from coal to oil in 1973 to comply with federal air pollution requirements, the coal stoker was not removed. It was, therefore, possible to reconvert the school to another form of solid fuel. After pursuing several alternatives, including wood chips from a location in Tennessee, the building was converted from burning oil to directly burning pelletized corn cobs purchased from a firm in Maumee, Ohio [72]. The corncob pellets have a heating value of approximately 8000 Btu per pound [5; 33:211,297]

and the fuel bill for the 1983 heating season was $6081.52 (101 tons of cobs). Critics of this project were quick to note that the winter of 1982-1983 was extremely mild. Dr. Mitchell Pedroff, assistant school superintendent, remarked: "even if we used twice as many corncob pellets, the fuel bill still would not be greater than those of the past [72]." In fact, Alternate Fuels of Ohio, the consultant to the school system, estimated that only 130 tons (less than $7850 at similar prices) would be required for a more normal heating season. This equates to estimated savings of approximately 58 percent based on a fuel oil cost of $1.00 per gallon [5]. The only residue remaining after firing was a small amount of ash which was collected in 30-gallon, domestic garbage cans and distributed in the area for use as fertilizer [72].

The current status of fermentation and pyrolysis technologies do not lend themselves easily to applications using municipal wastes. Fermentation organisms are generally feedstock specific and sensitive to inorganic materials, especially heavy metals. Additionally, both fermentation and pyrolysis need preparatory processing, such as sorting, chipping, and/or pulverization, in order to provide a homogenous feedstock before high efficiencies can be assured. A study of eight Army Ammunition Plants also showed that current pyrolysis units capable of servicing

these plants (50 tons per day input) would not be economically feasible, even under mobilization conditions [73:73]. However, recent work by the Solar Energy Research Institute, Boulder, Colorado, has developed a new process for converting biomass into medium-energy methanol which may change the economic outlook for pyrolysis [35:126]. Additionally, International Harvestor is studying the economic feasibility of portable waste-to-methanol units, and has demonstrated that the portable plants can have a return-on-investment three to four times that of a similiar sized stationary plant. These units will also have a 20 percent greater load factor, thus allowing them to compete with plants nearly five times as large [40:24]. The problems outlined above do not necessarily preclude the use of fermentation or pyrolysis in remote operation; however, direct combustion is less sophisticated and feedstock preprocessing is not as critical, especially in smaller units [90:1]. Therefore, direct combustion is more readily adaptible to the austere operating conditions and manning levels at remote sites.

An extremely effective waste-to-energy system consists of a waterwall boiler, a unit made of closely spaced steel tubes which circulate water or steam around the combustion chamber itself, producing process steam [95:4]. The United States Navy has been operating a refuse-fired,

waterwall system since 1967, this was probably the first DOD facility to use refuse as an energy feedstock [39:294]. This unit has continually demonstrated the effectiveness of this technology, but has shown that this type system is not economical unless 50 tons per day (tpd) of refuse can be fired in the facility [90:1]. Incinerators which recover discharged heat directly from hot flue gases and produce low pressure steam are the simplest conversion process for waste-to-energy systems [95:4].

There are examples of small scale direct combustion units which are in operation today. The community of North Little Rock, Arkansas has two small incinerators which burn garbage and produce enough steam for a nearby food processing plant [93:98]. The Agricultural Engineering building at the University of Maine is heated with a highly efficient wood burning furnace [16:86]. James Welty, of Redwood City, California, burns old auto seat covers, dashboards and floormats to generate 13,000 kilowatts of electricity per day using a surplus Navy generator [36:168]. Martin R. Lunde and Associates, Inc, a Minneapolis, Minnesota, alternative energy firm, offers a line of wood burning, water shrouded, long term storage boilers which could possibly be adapted for solid waste use. These boilers range in size from single family home units to units capable of handling the heating requirements of small office

buildings, dormitories or schools etc. and are designed to be integrated into existing forced air heating systems [64]. Although the Piqua project, outlined earlier, did not use municipal wastes, it is representitive of the type of system which could be used in remote site operations, especially if hot water or steam heating systems are already in place.

The most directly applicable example of a waste-to-energy system for remote operations was presented in a 1978 article in Management Review. The pyrolytic incinerator system shown in Figure 3 was installed at Rockwell International's Marysville, Ohio truck axle assembly plant and converts its accumulated trash (approximately 1,500 tons per year) into enough energy to entirely heat and cool the industrial areas of the plant without any mechanical preparation or atmospheric pollution. The cost to install this system in 1977 was $500,000 which included retro-fitting it to the plant's existing heating and air conditioning systems. It saved an estimated $110,000 annually by reducing energy (natural gas and electricity) consumption and virtually eliminating refuse collection expenses. These savings allowed the system to pay for itself in about four years. In addition, Rockwell is using dried cornstalks and corncobs from neighboring fields in the same unit to augment trash supplies. The result is power production, plus dry sterile

ash which can be used as fertilizer [49:43; 69; 85]. The flexibility and success of this system, including its very rapid economic payback, warrant further examination.

The following chapters will examine the question of whether a similar system could be installed at DOD remote sites and be used to effectively dispose of the site's solid wastes while contributing to the site's energy requirements as well.

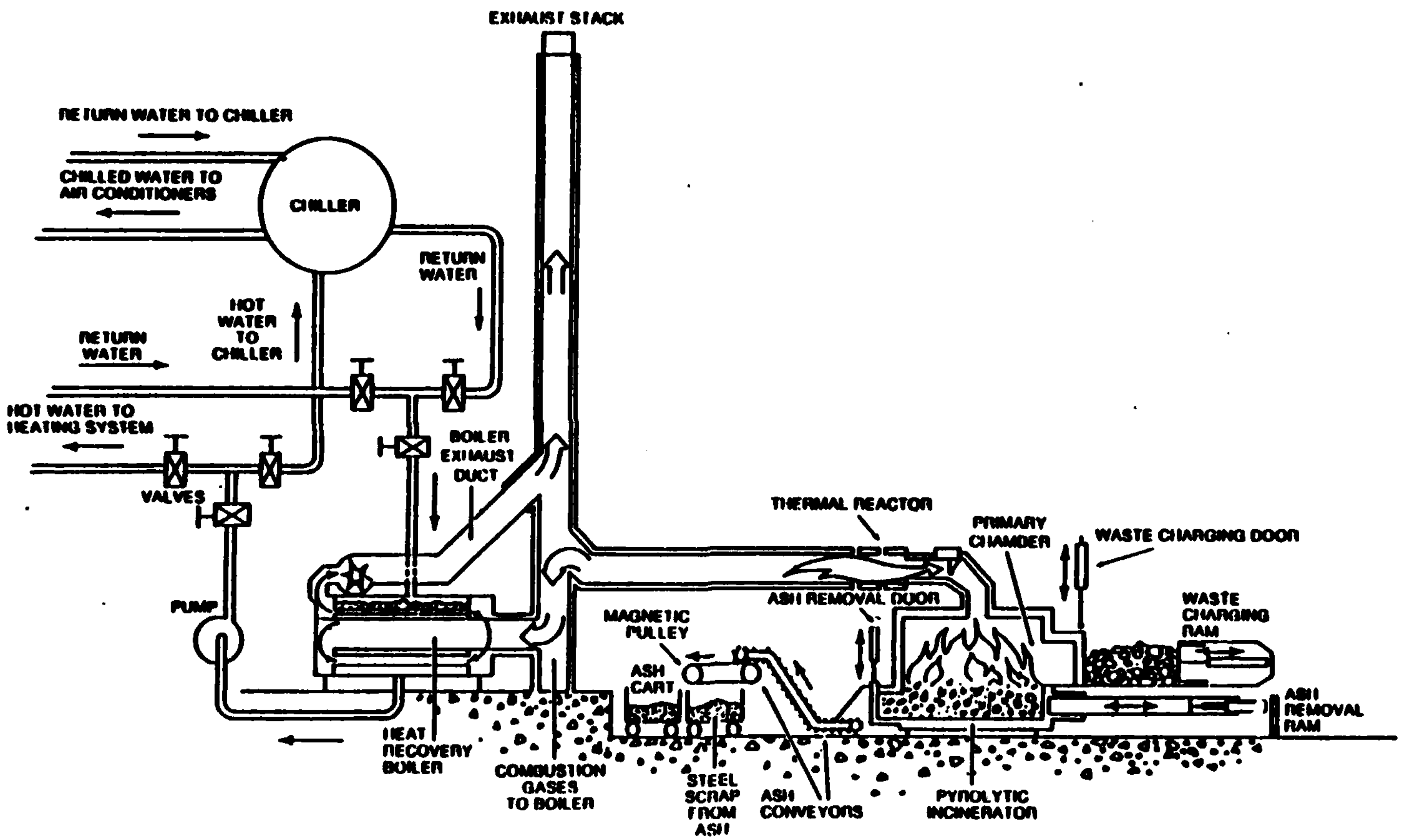

Figure 3. Rockwell Waste-to-Energy System [85]

CHAPTER III

METHODOLOGY

Economic analyses, the assessment of relevant costs and benefits associated with a particular project or undertaking, are central to decision making in the business community, however, they are tough to perform in the DOD context. Fisher, writing for the Rand Corporation in 1970, identified the problem as primarily one of assigning values to benefits which can be directly compared to dollar outlays. He stated there are four types of costs which must be evaluated in all economic analyses. They are:

1. Dollar expenditures,
2. Other costs that can be evaluated in dollars,
3. Other costs that can be quantified,
4. Other, nonquantifiable, costs [32:41].

The greatest problem in economic analyses in the DOD context is placing a value on benefits such as readiness, early warning, or national security in general. Fisher sums up these problems as follows:

> The important thing is not how we label costs and benefits, nor even which side of the equation they are on. The important thing is that all of the significant consequences of our decisions appear somewhere in our cost/benefit analyses and that they are neither forgotten nor double counted [32:43-4].

After reviewing the literature in both the alternative energy and solid waste disposal arenas, it was determined that the following types of data would be required in order to perform a valid cost/benefit analysis of a waste-to-energy system for remote site operations or CONUS bases, regardless of whether they are geographically remote or merely remote from their primary energy supplies:

1. Generation rates of solid waste for various population categories and/or industrial operations, including projected growth rates.

2. The characteristics of collected solid waste, including bulk density, moisture content, combustible fraction, and heating value (energy content).

3. Conversion efficiency of direct combustion incinerator systems.

4. Waste-to-energy plant construction and operating costs.

5. Revenue possibilities for waste-to-energy plants.

6. Solid Waste disposal costs that could be eliminated.

7. Conventional fuel savings, including both per unit costs and transportation costs.

8. Non-quantifiable benefits which might dictate that an unprofitable project should be undertaken regardless of economic indications.

As no waste-to-energy facilities of this scale were found in operation in the DOD currently, an extensive search of the energy conversion literature was conducted to obtain data on analagous systems with which to develop a cost estimating relationship and decision making tool to

determine the cost-effectiveness of waste-to-energy systems at remote locations. This search turned up a large amount of data concerning waste-to-energy systems; however most emphasized projects of a much larger scale than that required for remote site operations [30; 38; 39; 73; 90]. Aerospace Corporation, however, outlined an EPA model for small-scale modular incinerators which was applicable [2:70], and another applicable model was described by Schulz [82:428]. These models were used in a parallel set of calculations to determine the capital investments required for waste-to-energy plants and produced results similar to a sensitivity analysis.

Personal interviews were also conducted with two individuals who are working closely with alternative energy projects of this scale: 1) Mr. William A. Smith, retired facilities engineer at Marysville, who conceived, designed and installed the system for Rockwell International, and 2) Dr. Mitchell Pedroff, assistant superintendent of Piqua City Schools, who directed the search for and installation of the alternative energy system in one of the system's elementary schools.

A review of the refuse collection contract for military family housing of Wright-Patterson AFB was conducted to support the secondary hypothesis of this research: installation of a small-scale waste-to-energy unit

at CONUS bases. Telephone interviews were conducted with the managers of the two Dayton area refuse collection firms currently contracted by Wright-Patterson AFB, in order to obtain additional information which was not available from the contract performance reports.

When all these data were accumulated, the required size of a waste-to-energy facility was determined based on manning and population expectations and projected per capita waste generation estimates. The energy content of the solid waste expected was evaluated and converted into an energy equivalent of the conventional fuels it would replace. Following a methodology adapted from an Ultrasystems, Inc. study of biomass energy systems [15:20-31], several economic payback periods were calculated. The first series considered savings from displaced fuels as the only quantifiable revenue with which to defray the costs of construction and operation of a waste-to-energy facility. This is very nearly the case at remote sites. The next series of analyses evaluated the alternative revenues available to defray the costs at CONUS bases. The results of these analyses were then compared to the Air Force guidelines for energy associated construction.

CHAPTER IV

DATA DESCRIPTION AND ANALYSIS

The background research conducted for this study and outlined in the previous chapters indicated without a doubt that numerous waste-to-energy conversions are serious contenders in the race to secure energy independence for the United States. What now remains is to analyze the costs and benefits in a DOD context to determine if a small-scale waste-to-energy plant can be economically feasible for use at remote sites. Secondarily, a similar study should be performed addressing the use of this type facility at selected CONUS bases.

This chapter develops the information to determine an economic payback period for two waste-to-energy applications: 1) remote sites in general, and 2) specifically for the military family housing population at Wright-Patterson AFB, Ohio. First, future solid waste generation was estimated from historic data for both applications. These figures were used to determine the size facility required. Estimates of construction and operation and maintenance costs for these plants were developed using models found in the literature [2; 82;92]. Conventional fuel savings accrued by using solid waste were used to offset the costs of the facilities construction and operation. Additionally, other considerations to hasten the economic

payback for CONUS bases were examined. Throughout this chapter, the tabular data which are used in subsequent computations are annotated by the symbol '+'.

Generation of Solid Wastes

Historic generation. The per capita production of solid waste in the United States has been estimated by several researchers. Table 1 summarizes their findings.

TABLE 1

SUMMARY OF PER CAPITA SOLID WASTE GENERATION RATE STUDIES

Year	Study	Source of Waste	Pounds/day		Note
1971	EPA			3.3	1
1972	CERL	Army		5.4-5.7	1
		Navy		9.8-14.7	1
		Air Force		10.1-11.3	1
		Total Military		8.6-9.3	1
1973	Dugas	Residential	2.5		2
		Commercial	3.0		2
		Municipal	1.3		2
		Total	===>	6.8+	3
1974	Ohio			3.1	3
1975	California			4.7	3
1975	Denver, CO			4.0	3
1975	EPA			3.2	3
1975-6	USAF			4.7	3
1976	Thoryn			3.5	4
1978	Gordian Assoc.	Gross Discards	3.77+		5
		Recoverables	0.31		5
		Net Discards	====>	3.46	5

+. Used in future computations.

Notes: 1. Source: [2:24,154].
2. Source: [27:6-7].
3. Source: [2:22].
4. Source: [93:95].
5. Source: [38:16].

Growth Rates. Solid waste annual growth rate predictions range from 1.04 percent to 8 percent and are tabulated in Table 2.

TABLE 2

SOLID WASTE ANNUAL GROWTH PERCENTAGES

Source	Percentage Annual Growth
1973-1978 Growth Trend [38:19]	1.04
Franklin Associates, Ltd [38:19]	1.8+
Fernandos and Prokazka [31:145]	2.0
International Research & Technology [38:19]	2.6
United States Congress, Public Law 94-580 [8]	8.0

+. Used in future computations.

Projected Solid Waste Generation. Using the Franklin Associates estimate, a conservative 1.8 percent annually, selected values from Table 1 will increase to those shown in Table 3 by the year 2000.

TABLE 3

PROJECTED PER CAPITA SOLID WASTE GENERATION RATES
(pounds per day)

Source	Base year		1980	1985	1990	2000
EPA, 1971	1971	3.3	3.87	4.24	4.63	5.54
CERL, Air Force	1972	10.1	11.65	12.74	13.92	16.64
Dugas, Total	1973	6.8	7.70	8.42+	9.21	11.01
EPA, 1975	1975	3.2	3.50	3.82	4.18	5.00
USAF	1976	4.7	5.05	5.52	6.03	7.21
Thoryn	1976	3.5	3.76	4.11	4.49	5.37
Gordian Assoc.	1978	3.77	3.91	4.27	4.67+	5.58

+. Used in future computations.

Remote Site Operations. The solid waste generation projections for remote site operations based on several of the 1985 estimated per capita generation rates (Table 3) are shown in Table 4. One note about remote site operations is in order. During a surge or contingency operation those remote sites which are logistic transfer points and/or refueling stops will swell well above their normal population, thus placing additonal demands on the sites energy reserves, as well as significantly increasing the amount of solid waste generated. This scenario occurred at Ascension Island during the recent Falkland Islands War and has caused logisticians in both Great Britain and the United States to reassess the vulnerability of our remote site operations, particularly with respect to fuel. Consequently, I have projected generation rates for populations expected to be well above the ambient population of the site.

Using the Dugas rate because it includes both living and work related activities generating solid wastes, and using 2000 pounds per ton, a 1000 man remote site operation would produce feedstock for a waste-to-energy incinerator at the rate of 4.2 tons per day (tpd). If the expected surge population increased to 5000, and generated wastes at a rate similar to the normal rate, the fuel available for the incinerator would be 21 tpd. These figures will be used to

determine the plant size used in future computations.

TABLE 4

PROJECTED SOLID WASTE GENERATION AT REMOTE SITES
(pounds per day,1985)

Population	CERL,AF	Dugas	USAF	Gordian	EPA,1975
Per Capita	12.74	8.42	5.52	4.27	3.82
100	1274	842	552	427	382
500	6370	4210	2760	2135	1910
1000	12740	8420+	5520	4270	3820
2000	25480	16840	11040	8540	7640
5000	63700	42100+	27600	21350	19100
10000	127400	84200	55200	42700	38200

+. Used in future computations.

Wright-Patterson AFB Family Housing. There are 2348 family housing units at Wright-Patterson, which are currently maintained at a 95 percent occupancy rate because of extensive renovations underway. The normal Air Force goal for occupancy is 98.5 percent. The Wright-Patterson housing office estimates that an average of 2.5 persons live in each unit [87]. These facts provide an estimate of the population of family housing of approximately 5600 (5800 when renovations are complete). Using the most current estimate of gross solid waste generation rates (Gordian), this population will produce approximately 27086 (5800 X 4.67) pounds of solid waste in 1990 or 13.54 tpd.

Volume and weight of refuse collected from these units and delivered to a local landfill, mileage and number

of trips to the landfill, and man-hours expended during the period from February 1981 to June 1983 are shown in Table 5 and 6. The tonnage was computed based on the contractor's estimate of 700 pounds per cubic yard (0.35 tons per cubic yard) for the type of truck used to collect this refuse from family housing and deliver it to the area landfill [68]. (See Table 8 for alternate solid waste bulk densities which may be applicable in different situations.) The tonnage figures for 1982-83 reflect a drop in generation which is probably due to the reduced occupancy rates during renovation. The actual contract prices [96] for this time period were:

February 1981 to September 1981. . . $52,872
October 1981 to September 1982 . . . $83,640
October 1982 to September 1983 . . . $90,360.

The refuse collection contract data (average 13 tpd; 5.2 std dev) is considered more representative (of 1982), than the housing estimate. Therefore, an incinerator with a 15 tpd capacity (13.00 tpd projected at 1.8% per year) could dispose of the average refuse generated by Wright-Patterson's family housing population in 1990. A unit with a 22 tpd (18.52 tpd projected at 1.8% per year) capacity could handle a one standard deviation fluctuation, provided the variation increased at the same rate. These size requirements do not include the capacity to dispose of the refuse generated by the industrial activities of the

base, because data concerning projected generation was incomplete. This study therefore, considers only the refuse generated by the family housing population. There are two ways the additional refuse could be disposed of: 1) build the 22 tpd unit and dispose of industrial refuse when unused capacity allows, or 2) evaluate the waste generated by the industrial activities and build a waste-to-energy unit capable of handling all refuse generated at Wright-Patterson.

TABLE 5

WRIGHT-PATTERSON FAMILY HOUSING REFUSE COLLECTION; VOLUME AND WEIGHT [96]

	- cubic yards landfilled --					--Totals---		Tons/
Month	Mon	Tue	Wed	Thu	Fri	Yards	Tons	day#
Feb 1981	325	300	450*	350	-	1425	499	16.6
Mar	400	375	475*	375	-	1625	569	19.0
Apr	325	300	600*	450	-	1675	586	19.5
May	----- data incomplete -----							
Jun	325	400	450*	245	-	1420	497	16.6
Jul	250	225	525*	400	-	1400	490	16.3
Aug	350	325	475*	325	-	1475	516	17.2
Sep	250	400	325	300	325	1600	560	18.7
Oct	----- data missing --------							
Nov	300	225	225	250	275	1275	446	14.9
Dec	225	275	250	275	225	1250	438	14.6
Jan 1982	200	225	200	200	275	1100	385	12.8
Feb	225	200	175	100	100	800	280	9.3
Mar	225	150	125	125	125	750	263	8.8
Apr	----- data incomplete -----							
May	215	215	100	112	179	821	287	9.6
Jun	245	245	125	140	118	873	306	10.2
Jul	185	200	100	195	151	831	291	9.7
Aug	228	245	100	100	159	832	291	9.7
Sep	190	185	125	174	152	826	289	9.6
Oct	210	210	100	155	182	857	300	10.0
Nov	250	250	100	125	150	875	306	10.2
Dec	200	200	125	137	150	812	284	9.5
Jan 1983	231	187	100	100	112	730	256	8.5
Feb	186	163	107	124	124	704	246	8.2
Mar	169	200	105	155	124	753	264	8.8
Apr	136	124	80	124	155	619	217	7.2
May	265	173	118	118	173	874	306	10.2
Jun 1983	220	262	100	185	189	956	335	11.2
Total	6330	6259	2785	5339	3443	27131	9507	336.7
Average	243	241	139	205	172	1044	366	13.0+
Std Dev	61	73	64	104	60	332	116	5.2+
Months	26	26	20	26	20	26	26	26

Notes: Pick-up Schedule
Mon = West Page Manor
Tue = East Page Manor
Wed = Brick Housing
Thu = Woodland Hills
Fri = 420 Housing
* = Combined Brick & 420 Housing

#. Based on 30 day month
+. Used in future computations.

TABLE 6

WRIGHT-PATTERSON FAMILY HOUSING REFUSE COLLECTION:
MILEAGE AND LABOR [96]

Month	Mileage	Landfill Trips	Man-hours
Feb 1981	2141	57	320
Mar	2449	66	352
Apr	2503	67	432
May	-------- data incomplete ----------		
Jun	2716	56	408
Jul	2385	56	432
Aug	2223	59	408
Sep	2565	64	528
Oct	-------- data missing ------------		
Nov	2207	50	336
Dec	2259	50	368
Jan 1982	2034	44	336
Feb	1314	32	552
Mar	1268	29	456
Apr	-------- data incomplete ----------		
May	1500	33	408
Jun	1414	36	408
Jul	1195	35	504
Aug	1142	36	480
Sep	1160	36	384
Oct	1124	37	336
Nov	1110	35	352
Dec	1147	33	368
Jan 1983	1055	30	336
Feb	756	25	328
Mar	1010	29	368
Apr	856	22	336
May	1123	34	344
Jun 1983	1226	39	368
Total	41882	1090	10248
Average	1610.85	41.92	394.15
Std Deviation	624.57	13.36	64.94

Characteristics of Solid Wastes

Fractional Composition: Combustibles. Numerous studies determined the relative percentage composition of solid wastes collected throughout the country. These findings are summarized in Table 7.

TABLE 7

PERCENTAGE BY WEIGHT OF COMBUSTIBLE SOLID WASTE FRACTIONS

Material/Note	1	2	3	4	5	6
Paper	34.4	34.4	35.0	48.0	40.0	55.0
Plastics	3.9	3.9	4.0	4.0		1.8
Wood	3.2			14.0	4.0	2.6
Rubber				1.5		
Leather				1.5		
Rubber & Leather			3.0			1.8
Textiles			2.0	4.0	2.0	2.5
Rubber, Leather & Textiles	4.6					
Plastic, Rubber & Leather					6.0	
Food Wastes			15.0	12.0	17.0	16.0
Yard Wastes			16.0	2.0	10.0	13.7
Food & Yard Wastes	33.2					
Other		42.4				
Total % Combustible	79.3	80.7	75.0	87.0	79.0	93.4

Notes:

1. Residential and commercial solid waste, wet weight [38:20].
2. EPA figures reported in [38:6].
3. National Center for Resource Recovery estimate reported in [93:98].
4. Waste Characterization from an Army Installation [2:18].
5. Average composition [101:i].
6. Source: Fuels from Municipal Wastes for Utilities: Technology Assessment, Bechtel Corporation, March 1975, pp. 3-9, as reported in [92:XXI-6].

Bulk Density. The studies demonstrating bulk density, in pounds per cubic yard, of solid wastes are summarized in Table 8.

TABLE 8

BULK DENSITY OF SOLID WASTE

Source	Type Refuse	Pounds per cubic yard
Aerospace Corp (1)	Army	136
	Navy	178
	Air Force	137
	Total Military	152
SCA of Dayton (2)	Front-load truck	500
	Rear-load truck (3)	700
Koogler Suburban	(4)	400-1000
Gordian Assoc.(5)	Family housing	175.7 (sdev 11.7)
	Support	102.1 (sdev 7.6)
	Office	77.0 (sdev 8.2)
	Industrial	193.3 (sdev 21.5)
Gordian Assoc.(6)	Navy	107.9 (sdev 27.6)
Gordian ASSoc.(7)	Navy	93.5 (sdev 18.5)
Rigo (8)	Military	82

Notes:

1. 1972 Military Solid Waste Summary [2:24].
2. Wright-Patterson AFB, Ohio refuse collection contractor [68].
3. Type of truck used to collect waste in family housing at Wright-Patterson AFB [68]
4. Depends on type of refuse and compaction capabilities of pick-up vehicle [57].
5. 1978 solid Waste Survey at North Island NAS, CA [38:114].
6. March 1976 to March 1977 Surveys at 9 Naval bases. Range 74 to 166 pounds per cubic foot [38:119].
7. June 1977 Survey at North Island NAS, CA. Range 53 to 142 pounds per cubic foot [38:119].
8. Source: Rigo, H.G., "Characteristics of Military Refuse," in P. Beltz & J. Frankosky, eds., Proceedings of the ARPA Workshop on Waste-to-energy Conversion Systems for Military Base Utilization, Columbus, Ohio, 1974 as cited in [2:24,151].

Moisture Content. Moisture content is instrumental in determining the usable energy content of any fuel, including solid wastes. Estimates of solid waste moisture content range from 20 percent [12:134] to 30-31 percent [2:6; 12:134]. Military waste, because of higher than average industrial and administrative activities are generally drier than those collected from municipalities [2:16].

Energy Content. Estimates of the heating value of unprepared and densified solid wastes are summarized in Table 9.

TABLE 9

ENERGY CONTENT OF SOLID WASTES

Source	Preparation	Btu/pound
Barton [12:134]	As collected	4100-5500
	Densified	up to 6000
Chantland [18:80]	Densified	5500-6000
Anderson & Tillman [7:18]	As collected	5000-6000
Aerospace Corp. [2:6]	Military average	
	As collected	5000
Aerospace Corp. [2:12-14]	Family/Troop Support	
	As collected	4200-5600
	Sorted and dried	6600
	Military/Industrial	
	AS collected	6800-7500
	Sorted and dried	7200
Dugas [26:11]	Urban Wastes	5000
	Industrial Wastes	7200
Occidental [92:XXI-8]	10% moisture, densified	6300
Combustion Equip. [92:XXI-4]	Chemically treated	7500-8000

Energy Content of Other Fuels. In order to give a comparative feel for the heating value of solid wastes, several representative energy values for various fossil and biomass fuels are summarized in Table 10.

TABLE 10

COMPARATIVE HEAT VALUES OF VARIOUS FUELS

Fuel	Condition	Energy Content
Wood [83:3-4; 10:20]	Oven Dry	8300-8500 Btu/lb
Wood [10:20]	50% moisture	4830 Btu/lb
Wood Chips [46:3]	Green	4500 Btu/lb
Wood Chips [5]	45% moisture	4700 Btu/lb
Sawdust [46:3]	Green	4500 Btu/lb
Wood Pellets [46:3; 5]		7000-8000 Btu/lb
Grasses and grains [16:42]		7000 Btu/lb
Bagasse [16:62]	Dry	8000-9000 Btu/lb
Corncobs [33:211]	Dry	7961 Btu/lb
Corncobs [33:211]	9.6% moisture	7197 Btu/lb
Eastern Coal [5]		13,250 Btu/lb+
Western Coal [5]		9000 Btu/lb+
No. 2 Fuel Oil [46:3]		138,700 Btu/gal+
No. 6 Fuel Oil [46:3]		149,690 Btu/gal+

+. Used in future computations.

Solid Waste Disposal Costs

One way in which the investments in waste-to-energy facilities built in support of CONUS bases can be offset is through reduced refuse contract prices resulting from the fact that fewer trips will be made to landfills, thus avoiding "gate fees". The contractors serving Wright-Patterson AFB, Ohio use three primary landfills and the gate fees range from $1.85 to $2.35 per cubic yard or $5 to $20 per ton, depending on the specific landfill and the

type of refuse delivered [57; 68]. Both contractors also stated that several other factors are significant cost drivers in their operations:

1. Labor
2. Stops per mile
3. Type of truck
4. Distance from community to disposal site
5. Road conditions and topography [57; 68].

Labor is considered the most significant portion of operating costs. The type of truck used for pick-up influences labor costs; for example, a side-loader truck requires only a single operator whereas a rear-loader requires two. Additionally, the contractors estimate that 30-40 percent of their time and mileage is spent traveling to and from the disposal site. This is considered non-productive, and a 90 minute round-trip is considered a break-even distance to the disposal site [57]. In this study, the impact on payback periods of a conservative 10% contract price adjustment due to reduced mileage will be examined.

Waste-to-Energy Plant Costs

There are few cost figures available portraying the capital outlays involved to bring a waste-to-energy facility on line. Those which are available are figures for demonstration plants or plants for which construction was constrained, such as the EPA requirements that certain plants be built using "existing technology and off-the-shelf

equipment wherever possible [14:61]" to be eligible for government assistance. The industry has demonstrated daily input capacity as the apparent cost driver for estimating both capital investments and operating cost for future facilities; consequently, most of the costs have been reported in this context. Those which were not were converted to this basis for analysis.

Capital Investments for Construction. The capital construction costs for small to medium scale waste-to-energy and biomass facilities available are tabulated in Table 11. A study presented in 1977 at the Fourth Energy Technology Conference, Washington D.C., estimated construction costs for waste-to-energy incineration facilities to be approximately $40,000 per daily ton of capacity [82:428]. Another study, conducted by the EPA, estimated that construction costs for small, modular incineration units would be $15,000 (based on 1977 dollars) per daily ton of capacity, and that this relationship is linear up to the 200 ton per day size plant [2:70].

TABLE 11

WASTE-TO-ENERGY AND BIOMASS CAPITAL CONSTRUCTION COSTS

Facility	Type	Fuel	Capacity (tons/day)	Cost ($ x 1000)	#
1983 Lunde	LTSB	Wood, biomass	3.75	3.5	1
1977 Rockwell	INC	Waste, biomass	>4.5	500	2
1978 Brazil	Ethanol	Sugarcane, biomass	100	130000*	3
1980 Berglund	Ethanol	Corn	7.24	725.6	4
1981 Evergreen/ Texaco	Methanol	Wood chips, green	3500	250000	5
1982 Battelle Pacific	Methanol	Wood chips, dry	1984	146000*	5
Koppers/Babcock & Wilcock	Methanol	Peat, pulverized	2000	210000*	5
1974 Nashville	INC	Waste	720	13000	6
1977 Chicago	RDF	Waste	1000	14000	6
1975 Saugus	WW INC	Waste	1200	50000	7
Wheelabrator & Frye	WW INC	Waste	1000	30.8	8
Combustion Power	INC/ Turbine	Refuse, Air-classified	1000	22.5	8
Horner & Shilrin	Co-combustion	Shredded refuse	1000	10.4	8

INC = Incinerator; RDF = Mechanical Fuel Preparation;
WW INC = Waterwall Incinerator; LTSB = Long Term Storage Boiler.

#Notes: 1. Source: [64; 79:83].
2. Limiting capacity unknown. Source: [85].
3. Source: [40:25].
4. Source: [14:66-7]. Tons based on 258.5 bushels per day weighing 56 pounds per bushel at 13% moisture content [97].
5. Source: [40:24].
6. Source: [25:307; 39:294].
7. Source: [28:19].
8. Source: [92:XXI-5].
*. Estimates of projects not yet operational.

__Operating Costs__. Actual reported costs for operating waste-to-energy facilities of the desired scale are even more rare than construction cost figures for these facilities. The closest estimates for operating costs were developed for 1000 ton per day facilities using several different technologies [92:XXI-5] and are tabulated in Table 12.

TABLE 12

SOLID WASTE FACILITY OPERATING COSTS (1) [92:XXI-5]
(Plant Capacity 1,000 tons per day)

	Wheelabrator & Frye Waterwall Incinerator	Combustion Power Incinerator/ Turbine	Horner & Shilrin Co-combustion of Shredded Refuse
Labor and Supervision	3.40	3.10	2.59
Power	2.10	(2)	1.62
Other supplies	0.20	0.11	0.08
Maintenance	3.42	4.00	0.85
Miscellaneous	0.93	0.08	0.32
Disposal Costs	1.08	1.50	0.90
Total	11.13	9.48	6.36

Notes: 1. Costs are in 1976 dollars.
2. Self-generated.

Revenues from Waste-to-Energy Facilities

There are several ways to offset the costs of waste-to-energy conversion units. Among the most common are fees charged for depositing refuse, salvage of any recoverable materials discarded, and sale of any excess energy produced.

Disposal Fees. The Braintree, Mass. municipal incinerator (a 240 ton per day facility [39:294]) does not charge individual users at all and their fee for private, commercial haulers is a paltry $10 per truckload [67:61]. However, Barnett and Price reported disposal fees at waste-to-energy plants as having averaged between $10 to $15 per ton in 1979 [11:32]. Whatever fee (see section above entitled "Solid Waste Disposal Costs") is charged, waste-to-energy facilities' fees must compete with regional landfill gate rates, but

> the catch is that the best technological solutions (to solid waste disposal problems) are capital intensive and cannot compete as long as 'sanitary' landfills are available at a lower net disposal cost [82:427].

Material Recycling. Barnett and Price reported an average $3 to $5 per ton of revenue from recoverable material delivered to waste-to-energy facilities in 1979 [11:32]. Another example of revenues possible from recoverable material is Teledyne National of Baltimore's

contract to provide 15,000 tons of glass annually to Owens-Corning Fiberglass Corporation for $18.75 per ton. Finally, the Ames, Iowa municipal facility reports revenues of $100,000 annually from metal recovered from their feedstock stream. However, based on their daily capacity of 200 tons [39:294] and a 365 day year, this equates to only $1.37 per ton.

As an aside, an added advantage to the use of recycled materials, such as steel and aluminum, is the tremendous energy savings (52 and 96% respectively) accrued as opposed to original smelting of these materials [25:387].

Energy Sales. Barnett and Price have also reported 1979 average revenues from the sale of excess energy to be between $5 and $18 per ton of solid waste processed by waste-to-energy plants [11:32]. In a more specific example, the Onondago County, New York incinerator (a 1000 ton per day plant [39:294]) estimates it can produce process steam for $1.50 less ($7.50 vs $9.00) than area producers using natural gas. This shows process energy produced by waste-to-energy plants can successfully compete with that made by conventional producers [58:52].

Estimating Costs of Specific Waste-to-Energy Units

Construction Costs. Construction cost estimates for waste-to-energy units sized to meet the demands of remote

sites and the family housing population at Wright-Patterson, under the conditions outlined in previous sections of this report are tabulated in Table 13.

TABLE 13

WASTE-TO-ENERGY INCINERATOR CONSTRUCTION COSTS
(dollars per ton)

Capacity Required (tpd)	Remote Sites 4.2	21	Family Housing 15	22
Construction Costs				
$15,000/ton				
1977 dollars	63,000	315,000	225,000	330,000
1983 dollars	104,478+	522,388+	373,134+	547,264+
$40,000/ton				
1977 dollars	168,000	840,000	600,000	880,000
1983 dollars	278,607+	1,393,035+	995,025+	1,459,370+

+. Used in future computations.

Note: Conversion from 1977 to 1983 dollars computed using the military construction inflation index (1983 base year) of 0.603 IAW AFM 173-13 (1 Feb 1983), Table 5-1, pg 92. In 1983 dollars, $15,000 = $24,875.62 and $40,000 = $66334.99.

Operating Costs. If the operating and maintenance cost estimates for the Combustion Power Incinerator/Turbine and the Horner & Shilrin shredded refuse systems were applicable, they would yield the operating costs in Table 14. However, as these costs are for units much larger than those projected for this study, an estimated operating and maintenance cost of $5.00 per ton in 1976 was used. The reasoning behind this estimate was that the labor and supervision, power, and disposal cost elements must necessarily be dependent on scale of the unit, while the

maintenance and miscellaneous elements would probably not change much with scale.

TABLE 14

WASTE-TO-ENERGY INCINERATOR OPERATING COSTS
(dollars per ton)

Cost estimate	1976	1983	1985	1990
Combustion Power	9.48	16.78	18.54	23.14
Horner & Shilrin	6.36	11.26	12.44	15.53
Small scale estimate#	5.00	8.85	9.78+	12.20
Conversion index	0.565	1.000	1.105	1.379

+. Used in future computations; # = author's estimate.
Note: Conversion from 1976 to 1990 dollars computed using the O & M, non-POL inflation index (1983 base year) of AFM 173-13 (1 Feb 1983), Table 5-1, pg. 92.

Estimating Benefits of Specific Waste-to-Energy Plants

Fuel Savings. Based on a representative energy content of 5000 Btu per pound for family housing and 6000 Btu per pound for remote sites because of the industrial component of their refuse (Table 9), a waste-to-energy unit installed and operating at the capacities outlined above would conservatively replace the amounts of fuel oil or coal shown in Table 15.

TABLE 15

DAILY WASTE-TO-ENERGY FUEL SAVINGS

	Remote Sites		Family Housing	
Refuse burned (tpd)	4.2	21	15	22
(pounds)	8400	42000	30000	44000
Btu/pound (1)	6000	6000	5000	5000
Gross MBtu	50.40	252.0	150.0	220.0
Usable MBtu (2)	27.72	138.6	82.5	121.0
Equivalents (daily)				
#2 Fuel oil (3)	199.9g	999.3g		
#6 Fuel oil (4)	185.2g	925.9g		
Eastern coal (5)			3.11t	4.57t
Western coal (6)			4.58t	6.72t
Savings (daily)				
#2 Fuel Oil				
$1.00/gal	$199.90	$999.30		
$1.10/gal	219.89	1099.23		
$1.20/gal	239.88+	1199.16+		
$1.30/gal	259.87	1299.09		
$1.40/gal	279.86	1399.02		
$1.50/gal	299.85	1498.95		
#6 Fuel Oil				
$1.00/gal	185.20	925.90		
$1.10/gal	203.72	1018.49		
$1.20/gal	222.24+	1111.08+		
$1.30/gal	240.76	1203.67		
$1.40/gal	259.28	1296.26		
$1.50/gal	277.80	1388.85		
Eastern coal				
$70/ton			$217.70	$319.90
$80/ton			248.80+	365.60+
$90/ton			279.90	411.30
$100/ton			311.00	457.00
Western coal				
$40/ton			183.20	268.80
$50/ton			229.00+	336.00+
$60/ton			274.80	403.20
$70/ton			320.60	470.40

+. Used in future computations.

Notes: 1. See Table 9.
2. Based on 55% efficiency [74:70].
3. 138,700 Btu/gal
4. 149,690 Btu/gal
5. 13,250 Btu/lb
6. 9,000 Btu/lb

Economic Payback Periods

Economic payback periods are computed by subtracting operating costs from the benefits derived from the operation, such as conventional fuel savings, or reduced refuse collection contract prices. The funds remaining are then used to defray the construction costs of the facility. These funds are simply divided into the construction cost estimate to compute the period of time required to completely payback the investment. The Air Force guideline for acceptable economic payback periods is 10 years from the time the facility opens for energy related construction [44].

Payback Based on Fuel Savings Alone. Table 16 outlines the computation of economic payback in years for the proposed systems based solely on conventional fuel savings. This table is particularly illustrative in the case of remote operations as there are few means other than fuel savings available to offset the capital investments. However, there are numerous other revenues and savings available to amortize the cost of waste-to-energy investments at CONUS bases which will be detailed later. It may be possible to reduce the payback period at remote sites by adjusting the price of the refuse collection contract, but this must be evaluated on a site by site basis to determine its impact.

TABLE 16

FUEL SAVINGS WASTE-TO-ENERGY ECONOMIC PAYBACK PERIODS

	Remote Sites		Family Housing	
Daily savings/ton				
$1.20/gal #2 fuel oil	57.11*			
$80/ton Eastern coal			16.60*	
Operating costs	9.78		9.78	
	-----		-----	
Daily amortization	47.33		6.82	
Annual amortization	17,275.45+		2489.30+	
Plant capacity (tpd)	4.2	21	15	22
Payback (yrs)#				
$15,000/t estimate	6.05	30.24	149.90	219.85
$40,000/t estimate	16.13	80.64	399.72	586.26
Daily savings/ton				
$1.20/gal #6 fuel oil	52.91*			
$50/ton Western coal			15.27*	
Operating costs	9.78		9.78	
	-----		-----	
Daily amortization	43.13		5.49	
Annual amortization	15,742.45+		2003.85+	
Plant capacity (tpd)	4.2	21	15	22
Payback (yrs)#				
$15,000/t estimate	6.64	33.18	186.21	273.11
$40,000/t estimate	17.70	88.49	496.56	728.28

+. Used in future computations.
#. The estimate labels refer to the 1977 dollar values, however, all of the information in the table has been converted to the applicable current or projected dollar values.
Payback = Estimated construction costs divided by annual amortization amount.
*. Values in Table 15 are divided by plant capacity.

A remote site incinerator, whose construction costs are $104,478 ($24,875.62/tpd,1983 dollars), is economically feasible (using the 10 year payback guideline) when considering only the conventional fuel savings. In fact,

with the projected fuel savings, this facility could have construction costs of between $157,424.50 and $172,754.50, depending on the fuel being replaced, and still meet the 10 year guideline. The CONUS base scenarios are not economical using conventional fuel savings alone to offset the construction costs. However, there are several additional considerations concerning CONUS bases.

Additional Considerations for CONUS Bases. CONUS bases have additional revenues besides conventional fuel savings which can be used to defray or amortize waste-to-energy investments. These are highlighted by the example in Table 17. The recoverable item revenue estimate is the low range reported in 1979 [11:32] and therefore, $14,235 and $22,995 are conservative estimates of the revenue available from recyclable goods. Another means of offsetting investments in waste-to-energy units is reductions in refuse collection contract prices at bases operating refuse incinerators (as mentioned earlier this may also be applicable to certain remote sites). These reductions would be possible because the contractor would no longer have to pay "gate fees" for disposal of the refuse collected. Also, the mileage required to deliver refuse to a disposal site located on base would be reduced [60:63]. These reduced contractor costs would allow the price paid for refuse collection to be reduced and the possible impact

of these reductions is shown in Table 17. The payback is shorter if the analysis assumes that the facility produces an excess amount of energy which could be sold to neighboring customers, however, it does not seem that this would be the case at a highly industrialized base such as Wright-Patterson.

TABLE 17

ANNUAL WASTE-TO-ENERGY ECONOMIC PAYBACK AT CONUS BASES

Fuel Used	Eastern Coal		Western Coal	
Plant Capacity	15	22	15	22
Estimated refuse contract	$85,000	$135,000	$85,000	$135,000
Amortization Fund Sources				
Fuel savings (Table 16)	2489.30	2489.30	2003.85	2003.85
Recoverables $3/ton	14235.00	22995.00	14235.00	22995.00
10% Mileage reduction	8500.00	13500.00	8500.00	13500.00
Gate Fees $5/ton	27375.00	40150.00	27375.00	40150.00
Total annual amortization*	52599.30	79134.30	52113.85	78648.85
Payback (yrs)#				
$15,000/t	7.09	6.92	7.16	6.96
$40,000/t	18.92	18.54	19.09	18.56

Notes: *. Total annual amortization funds are the sum of fuel savings, recyclable material revenues, mileage reduction, and gate fee reductions.

#. The estimate labels refer to the 1977 dollar values, however, all of the information in the table has been converted to the applicable current of projected dollar values.
Payback = Estimated Construction Costs divided by annual amortization amount.

Under the scenario described by this study, a waste-to-energy unit, whose estimated construction costs are approximately $24,875.62 (1983 dollars) per tpd of capacity, could be built at Wright-Patterson to dispose of the average waste generated in 1990 or a one standard deviation increase, and it would comply with the 10 year guideline for payback of energy construction investments.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

At the beginning of this study, it was hypothesized that: a small-scale energy unit, using fuels derived from wastes or biomass, can be incorporated into remote site energy systems for a reasonable cost, which will contribute to the alternative energy goals for the site, while simultaneously helping to solve the site's solid waste disposal problems. Similarly, it was also hypothesized that an alternate energy system could be developed which would simultaneously help reduce the rising costs of solid waste disposal and energy consumption at CONUS bases. The economic analysis developed and performed in Chapter 4 clearly supports construction of a waste-to-energy facility to handle normal solid waste generation at remote sites under the assumptions of the study. Specifically, construction costs can be amortized within current guidelines based on the projected energy potential of the waste generated by the population at the site. The assumptions of the study also support the construction of a waste-to-energy facility at Wright-Patterson AFB if the construction costs can be kept under approximately $25,000 per tpd of capacity.

Considerations

There are circumstances which, if considered in more depth, could strengthen the support this study gives to, waste-to-energy conversion:

1. The majority of the cost data presented here are from projects, many of which were demonstration projects, on the leading edge of research and development. As experience is gained by contractors and operators the costs of these facilities will decrease while the benefits increase.
2. The costs of air pollution equipment can be reduced when solid wastes are incinerated properly, either alone or in conjunction with coal, because of their extremely low sulfur content.
3. The useful energy content of solid wastes used for fuel could be increased if the plant is designed so that the exhaust gases from the incinerator are directed at the feedstock in order to reduce fuel moisture content.
4. The cost-effectiveness of CONUS base waste-to-heat plants could be increased if local refuse collectors were allowed to dispose of refuse from the surrounding communities at the site as well. If a nominal fee were charged, it would hasten the payback. If no fee were charged, the increased supply of fuel would

enhance the system's reliablity while the recoverable materials collected would hasten the payback of the plant.

5. Energy solutions should not be collected and held in order to solve the entire energy problem with a single effort. One benefit of each proposed concept and project must be its unique contribution, regardless of size, to the overall problem. Consideration of some projects which do not demonstrate clearcut short-term profitability could have a very positive effect on energy research and development because every step we take will quicken the pace as others see what can be accomplished.

Each of the ideas above are benefits which are extremely difficult to quantify, and therefore will require some judgement calls from our DOD decision makers in order to assure the best course of action is pursued.

Recommendations

Specific areas for further research which will provide significant benefits to the DOD and Air Force are:

1. The Scandanavian pulp and paper industry has developed an alternate technique for economic analyses concerning energy replacement construction [71:37]. It combines interest rates on capital, inflation rates, and conventional fuel escalation rates into a

composite, effective interest rate which is then used to determine economic feasibility. The index numbers of AFM 173-13 should be evaluated to see if a similar composite interest rate should be used in lieu of the overall military construction indices to improve analyses of energy related construction projects.

2. Transportation costs seem to be the first cost element which disqualify waste-to-energy use under normal economic analysis, especially if coal is the fuel being replaced or co-firing with coal is considered. The industrial nature of operations at many installations produces a large amount of high energy refuse. Therefore, since coal-fired boilers exist at several installations, the feasibility of erecting a refuse preparation facility at these bases should be examined. This would allow refuse derived fuels to be more competitive with coal, while at the same time reducing the burden on local landfills surrounding the installation.

3. In a similar fashion, a refuse preparation facility (shredder or pelletizer), in conjunction with a pyrolytic or fermentation unit, should be examined as a refuse disposal alternative at installations where oil or natural gas are used to provide energy.

4. The economic impact of a preparation facility and a fermentation or pyrolysis unit operating together to convert wastes into a fuel which can be used in DOD ground transportation vehicles should be determined.

5. The feasibility of the portable methanol units, being developed by International Harvester (or similar units), being used to provide mobility fuels for contingency or combat operation of ground transportation should be investigated.

6. A methodology should be developed to determine the overall energy requirements of specific facilities and/or sites so that the portion of the requirements which can be transferred to a waste-to-energy or biomass system can be determined.

7. Finally, waste-to-energy facilities of the kind described in this study and proven effective by Rockwell International and the Piqua City Schools should be more seriously considered in planning exercises throughout the DOD. Because of the feedstock flexibilty of the Rockwell system, serious thought should be given to using the biomass resources readily available surrounding many DOD installations to augment the refuse fuel. Many acres of government land are currently leased to private citizens for

agriculture or timber management [62; 99]. The residues from these leases represent a vast amount of very cheap energy if a facility is available to convert it.

One Final Thought

> The nation should deliberately broaden its options by pursuing an array of (energy) technologies, even if one or a few seem clearly preferable. The unexpected may happen, and for environmental or other reasons we may wish to abandon some sources of supply. If good alternatives are available, the switch can be made at reasonable cost. More important, with reasonable options available, there will be less temptation to continue using an undesirable source [80:42].

> Each increase in the price of conventional fuel widens the scope of feasible alternatives and lowers the threshold size of the potential contribution that makes investigation worthwhile [80:42].

> The advantage of tapping the solar energy stored in green plants and organic wastes is that it could provide a fuel source to replace our dwindling fossil fuel supplies which is both renewable and available in our own time [26:1].

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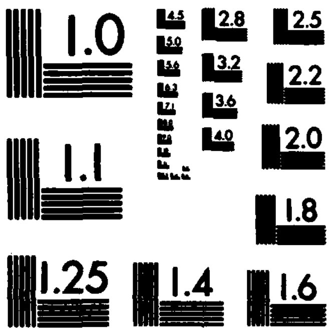

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